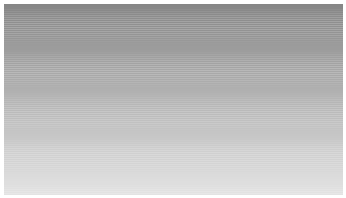

End of Project Report

May, 2001

ARMIS No. 4383

CHARACTERISATION OF FEEDSTUFFS FOR RUMINANTS

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ISBN 1 84170 2110

Teagasc acknowledges with gratitude the support of the European Union Structural Funds (EAGGF) in financing this research project

Beef Production Series No. 32

GRANGE RESEARCH CENTRE,
Dunsany,
Co. Meath
ISBN 1 84170 2110
May 2001

Teagasc
Agriculture and Food Development Authority

EUROPEAN UNION
European Agricultural Guidance and Guarantee Fund

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SUMMARY AND CONCLUSIONS

A wide variety of feed ingredients are used in the manufacture of compound feeds in Ireland. Unprocessed feedstuffs vary from batch to batch due to differences caused by variety, soils, weather, etc. By -product feeds may also vary due to the processes from which they were produced. Accurate information on the nutritive value of feeds is essential for accurate ration formulation. A series of experiments was carried out to determine various nutritional characteristics of concentrate ingredients either locally produced or imported into Ireland. From these experiments it was concluded that :

* The digestibility values of concentrate ingredients derived in maintenance-fed sheep are applicable to maintenance-fed cattle.
* Feed is not utilised as efficiently when the level of feeding is increased from maintenance to 2 x maintenance.
* The improved feed conversion efficiency in steers offered a restricted allowance of concentrates cannot be attributed to a difference in digestibility but can be attributed in part to a lower rate of fat deposition compared to steers offered *ad libitum* concentrates.
* The residue after oil extraction from *Camelina sativa* could replace some imported protein-rich feedstuffs in ruminant rations but to fully achieve this potential, the residual oil content must be decreased.
* For measurement of ruminal degradability of concentrate ingredients a wide range of forage to concentrate ratios and feeding levels can be used.
* It is important to consider the actual outflow rate of nutrients from the rumen when measuring the feed value of individual concentrate ingredients as this can have an impact on the effective degradability and the relative nutritive values assigned to such ingredients.
* Large variations in ruminal degradation occur within and

among feeds. The ruminal degradability of different samples of any one feed should be measured to determine their true nutritive value for feeding ruminants.

* Within most concentrate ingredients examined, the variation in small intestinal digestibility (SID) due to source indicates a range in the quantity of amino acids supplied to the animal for productive purposes. The more rapid and cost effective *in vitro* technique can be used to screen the SID of concentrate ingredients.
* Target volatile fatty acid (VFA) concentrations and proportions may be produced by varying the proportions of the individual ingredients in a concentrate ration.
* An *in vitro* procedure allowed VFA production to be measured across a large range of feeds under standardised conditions.
* On average, 75% of gas produced during ruminal fermentation consists of carbon dioxide. The variation in methane production among individual concentrate ingredients provides an opportunity to formulate rations to minimize environmental pollution with methane.

INTRODUCTION

A wide variety of feed ingredients is used in the manufacture of compound feeds in Ireland. Some are home produced but many are imported. Some are whole unadulterated feeds such as cereal grains (barley, wheat, oats and maize) but most are by-products of some industrial process. Feeds vary from batch to batch due to differences caused by variety, soils, weather, etc. By-product feeds tend to be more variable due to the processes they have undergone. For correct formulation of rations, nutritionists must have accurate information regarding the nutrient value of available feeds. Such information is generally obtained from published databases developed abroad. United Kingdom, French and Dutch databases are widely used in Ireland. These have the disadvantage of being non-specific to Ireland. Thus, feeds produced locally could differ compared to the same feed produced in other countries, and different grades of the by-product feeds could be imported to Ireland than to other countries. In addition, the composition of feeds and especially by-products changes over time due to change in varieties and manufacturing processess.

The objective of this project was to produce a database of the nutritive value of concentrate ingredients either locally produced or imported into Ireland with a particular emphasis on their ruminal degradability and small intestinal digestibility.

Experiment 1 : Comparison of digestibility in sheep and cattle

The digestibilities of ruminant feeds are often determined using sheep rather than cattle as the experimental unit. This reflects the smaller quantities of feed required and the convenience associated with using the smaller species. The digestibility values obtained with sheep are often applied to cattle with the assumption that sheep and cattle have equal digestive abilities, yet there is little information available to justify the application of sheep results to cattle. Many feed evaluation systems use digestibility data derived from sheep offered feed at approximately maintenance energy level. A constant depression of digestibility (4% for each multiple increase in intake over maintenance) is frequently assumed but there are data to suggest that this is not always the case.

Accordingly, the effect of animal species (cattle or sheep) and level of feeding (maintenance and 2 x maintenance) on the digestibility of concentrate ingredients were examined. Twelve Friesian steers, bodyweight (BW) 351kg (sd 18.9) were assigned to blocks of two on a descending BW basis. Each block was assigned to an incomplete (four periods), six (animals) by six (period) Latin Square. Animals in one of the squares were offered feed at maintenance and animals in the second square were offered feed at 2 x maintenance. Twenty four wether sheep, BW 40.2kg (sd 3.77) were used simultaneously and offered feed at maintenance with four sheep being randomly allocated to each treatment. The treatments were copra meal, sunflower meal, dry corn gluten feed (Archer Daniels Midland Company (ADM)), dry corn gluten feed (Cargill), soya hulls and palm kernel meal. The digestibilities of dry matter (DM), organic matter (OM), crude protein (CP) and gross energy (GE), were measured in both species (Table 1).

Table 1a. Dry matter digestibility (g kg^{-1}) of concentrate ingredients in cattle or sheep fed at maintenance and in cattle fed at maintenance and 2 x maintenance

	Sheep (a)	Cattle (b)	Cattle (c)
	Maintenance	**Maintenance**	**2 x Maintenance**
Copra meal	707.7	693.5	618.2
Sunflower meal	509.9	540.4	508.9
ADM gluten	701.6	724.7	654.0
Cargill gluten	710.5	743.7	640.1
Soya hulls	781.5	767.9	658.5
Palm kernel meal	614.7	604.2	498.2
Cattle-sheep comparison ((a) and (b))	**Significance**		**sed**
Species	NS		8.60
Ingredient	***		14.90
Species x ingredient interaction	NS		21.07
Level of feeding comparison ((b) and ((c))	**Significance**		**sed**
Level	***		9.60
Ingredient	***		16.62
Level x ingredient interaction	NS		23.51

(a): Digestibilities of concentrates in sheep fed at maintenance
(b): Digestibilities of concentrates in cattle fed at maintenance
(c): Digestibilities of concentrates in cattle fed at 2 x maintenance

Table 1b. Organic matter digestibility (g kg^{-1}) of concentrate ingredients in cattle or sheep fed at maintenance and in cattle fed at maintenance and 2 x maintenance

	Sheep (a)	Cattle (b)	Cattle (c)
	Maintenance	**Maintenance**	**2 x Maintenance**
Copra meal	721.6	698.6	626.8
Sunflower meal	524.1	552.8	525.2
ADM gluten	739.0	760.6	680.7
Cargill gluten	746.0	766.8	673.7
Soya hulls	794.4	786.1	673.8
Palm kernel meal	638.1	639.6	535.8
Cattle-sheep comparison ((a) and (b))	**Significance**	**sed**	
Species	NS	9.45	
Ingredient	***	16.37	
Species x ingredient interaction	NS	23.17	
Level of feeding comparison ((b) and ((c))	**Significance**	**sed**	
Level	***	9.27	
Ingredient	***	17.27	
Level x ingredient interaction	NS	24.13	

(a): Digestibilities of concentrates in sheep fed at maintenance
(b): Digestibilities of concentrates in cattle fed at maintenance
(c): Digestibilities of concentrates in cattle fed at 2 x maintenance

Table 1c. Crude protein digestibility (g kg^{-1}) of concentrate ingredients in cattle or sheep fed at maintenance and in cattle fed at maintenance and 2 x maintenance

	Sheep (a)	Cattle (b)	Cattle (c)
	Maintenance	Maintenance	2 x Maintenance
Copra meal	571.8	488.6	418.9
Sunflower meal	792.9	783.7	746.2
ADM gluten	697.2	676.0	648.8
Cargill gluten	714.7	712.0	628.8
Soya hulls	471.3	517.5	428.7
Palm kernel meal	581.8	414.5	188.6
Cattle-sheep comparison ((a) and (b))	**Significance**	**sed**	
Species	*	16.70	
Ingredient	***	28.93	
Species x ingredient interaction	*	40.91	
Level of feeding comparison ((b) and ((c))	**Significance**	**sed**	
Level	***	17.63	
Ingredient	***	30.53	
Level x ingredient interaction	*	43.18	

(a): Digestibilities of concentrates in sheep fed at maintenance
(b): Digestibilities of concentrates in cattle fed at maintenance
(c): Digestibilities of concentrates in cattle fed at 2 x maintenance

Table 1d. Gross energy digestibility (g/kg^{-1}) of concentrate ingredients in cattle or sheep fed at maintenance and in cattle fed at maintenance and 2 x maintenance

	Sheep (a)	Cattle (b)	Cattle (c)
	Maintenance	**Maintenance**	**2 x Maintenance**
Copra meal	683.5	658.1	585.2
Sunflower meal	524.2	554.1	519.2
ADM gluten	726.5	747.9	669.2
Cargill gluten	737.1	761.6	660.5
Soya hulls	765.0	755.7	646.6
Palm kernel meal	628.4	619.5	512.4

Cattle-sheep comparison ((a) and (b))	**Significance**	**sed**
Species	NS	8.02
Ingredient	***	13.89
Species x ingredient interaction	NS	19.65

Level of feeding comparison ((b) and ((c))	**Significance**	**sed**
Level	***	8.91
Ingredient	***	15.43
Level x ingredient interaction	NS	21.82

(a): Digestibilities of concentrates in sheep fed at maintenance
(b): Digestibilities of concentrates in cattle fed at maintenance
(c): Digestibilities of concentrates in cattle fed at 2 x maintenance

Sheep had a significantly greater ability to digest CP than cattle. Increasing the level of feeding decreased the digestibilities of DM, OM, CP, and GE, ($p<0.001$). It is concluded that the digestibility values of concentrate ingredients derived in maintenance-fed sheep are applicable to maintenance-fed cattle for DM, OM, and GE In addition, the digestibility of concentrate ingredients was significnatly depressed with an increase in level of feeding ($p <0.001$), for all digestibility components. Therefore, it is concluded that feed is not utilised as efficiently when the level of feeding is increased from maintenance to 2 x maintenance.

Experiment 2. Growth, feed conversion efficiency and diet digestibility of steers offered *ad-libitum* or restricted allowance of concentrates

Restricting the allowance of feeds typically used in U.S. feedlot production systems has been shown to reduce liveweight gain but to improve the efficiency of conversion of dietary DM to carcass weight when compared to *ad-libitum* concentrates. Possible explanations for the poorer feed efficiency in cattle fed *ad-libitum* are reduced activity, decreased diet digestibility and increased body fat accumulation (i.e. less weight gain at similar energy retention per kg feed). As increased intake resulted in a depression in digestibility in Experiment 1, the objective of this experiment was to quantify the effect on diet digestibility, feed conversion efficiency and steer performance of restricting the allowance of concentrates more commonly used in Ireland.

Twenty four continental crossbred steers (494 kg) were blocked on descending liveweight and assigned at random to either concentrates offered *ad-libitum* or concentrates restricted to 0.71 of *ad-libitum* DM intake. The pelleted concentrate, which was a mixture of ground barley (0.46), unmolassed sugar beet pulp (0.42), soyabean meal (0.08), tallow (0.01) and a proprietary mineral/vitamin mix (0.03), was offered individually to all animals. Animals on the restricted allowance were offered their daily concentrate allowance in two equal feeds.

All animals were also offered 1 kg hay daily and were slaughtered after an 85-day experimental period. Twelve Friesian steers (458 kg) were randomly assigned to DM allowances of either 19.9 or 14.4 g DM/kg bodyweight which were equivalent to both the DM intake and the hay to concentrate ratio of the steers in the growth study offered *ad-libitum* or restricted concentrate allowances, respectively. Animals were allowed two weeks to adjust to their diets, prior to measurement of complete diet digestibility.

The steers offered the *ad-libitum* and restricted allowances of concentrates consumed 11.2 and 7.9 kg DM respectively, plus 0.8 kg hay DM. Increasing concentrate intake increased liveweight gain ($p < 0.001$), carcass gain ($p < 0.01$), fat score ($p < 0.05$) and internal fat proportions ($p < 0.001$) and decreased feed conversion efficiency ($p < 0.05$) (Table 2). There was no effect of concentrate allowance on diet digestibility or carcass conformation score.

It is concluded that the improved feed conversion efficiency in the animals offered a restricted allowance of concentrates cannot be attributed to a difference in digestibility but can be attributed in part to a lower rate of fat deposition compared to steers offered *ad-libitum* concentrates.

Table 2: The effect of concentrate allowance on growth, efficiency and diet digestibility in steers

	Concentrate allowance			
	Ad-libitum	**Restricted**	**s.e.**	**Significance**
Liveweight gain (kg/day)	1.33	0.91	0.048	***
Carcass gain (kg/day)	0.76	0.61	0.026	**
Carcass fat score	4.11	3.41	0.165	*
Internal fat (g/kg carcass)	29	17	1.4	***
Carcass conformation	2.58	2.75	0.191	n.s.
Digestibility (g/kg)				
Dry matter	745	762	12.1	n.s.
Crude protein	672	691	20.2	n.s
Organic matter	846	858	7.9	n.s.
NDF[1]	888	894	5.4	n.s.
ADF[1]	609	658	21.0	n.s.
Gross energy	771	789	12.0	n.s.
Feed conversion efficiency	16.2	13.9	1.1	*

[1]NDF = Neutral detergent fibre; ADF = acid detergent fibre
kg feed DM consumed per kg carcass gain

Experiment 3. The nutritive value of camelina meal for beef cattle

Camelina sativa, a member of the mustard family, is a summer flowering annual oilseed crop. The crop is well adapted to Irish conditions and can be produced with only minor adjustments to existing farm machinery. Of particular interest is the crop's high oil content (43%) and high content of polyunsaturated fatty acids (85%). Following oil extraction, approximately 50% of the seed mass is recovered as an oilseed cake. The objective of the study was to provide preliminary information on the nutritive value of this cake (meal) as a feed for beef cattle.

Oil was extracted from the camelina by cold pressure using a cold press, KOMET single screw vegetable oil expeller. The resultant meal had the following chemical composition: DM 865 g/kg, CP 313 g/kg DM, ash 51 g/kg DM and Oil B 260 g/kg DM. Dry matter digestibility measured *in vitro* was 609 g/kg. Because excessive lipid consumption can impair microbial growth and metabolism in the rumen, the impact of decreasing the amount of camelina meal used in the standard *in vitro* assay was examined. The relationship between camelina meal inclusion (x) and digestibility (y) was $y = 0.55 (x) + 13.1$, $R^2=0.99$. This indicates that the high oil content of camelina meal did not influence microbial activity in this assay. To measure the intake potential of camelina meal, it was offered *ad libitum* together with 2 kg of hay (DM, 812 g/kg, *in vitro* DM digestibility 680 g/kg) to four individually penned steers (bodyweight = 417 kg) for a 12 day adaptation period followed by a 10 day intake measurement period. Mean daily camelina meal DM intake during the latter phase was 3.3 (se 0.25) kg.

When the hay allowance was restricted to 1 kg per animal daily, camelina meal consumption was 3.8 (s.e. 0.25) kg/day. *In vivo* digestibility of camelina meal in the latter ration and of three protein-rich ingredients (sunflower meal, corn gluten and copra meal; 3.7 kgplus 0.7 kg hay per animal daily) were measured by total collection of faeces. The digestibility of the meals was calculated by difference assuming

constant digestibility coefficients for the hay. For camelina meal, sunflower meal, corn gluten and copra meal, digestibility of DM was 690, 540, 744 and 694 (s.e.d. 34.2) g/kg, respectively. The corresponding values for organic matter, CP and oil were 722, 553, 767 and 699 (s.e.d. 33.2) g/kg, 771, 782, 712 and 489 (s.e.d. 33.2) g/kg, and 755, 814, 830 and 717 (s.e.d. 54.8) g/kg. It is concluded that camelina meal could replace some imported protein-rich feedstuffs in ruminant rations but to fully achieve this potential, the residual oil content must be decreased.

Experiment 4. Ruminal degradability of concentrate ingredients in steers offered diets varying in feeding level and the ratio of grass silage to concentrate

Modern feed evaluation systems for ruminants recognise the importance of the rate of degradation of protein and energy yielding substrates in the diet. The *in sacco* technique is widely used to characterise the degradability of feeds in the rumen. Grass silage is a more commonly used source of roughage than hay in Ireland and there is little information on the effect of grass silage inclusion in the basal diet on the DM disappearance of concentrate ingredients. The objectives of this experiment were to further standardise the *in sacco* procedure for Irish conditions by examining the effects of (a) level of feeding, and (b) grass silage:concentrate ratio, on the DM degradability of concentrate ingredients in steers.

Six ruminally-fistulated steers were used in a 6 (treatments) by 6 (periods) Latin square design with a 3 (silage:concentrate ratios) by 2 (levels of feeding) factorial arrangement of treatments. Animals were offered 250, 500 and 750 g grass silage DM per kg total diet. The pelleted concentrate contained six test feeds (copra meal, corn gluten, soya hulls, barley, fishmeal and soyabean meal) together with citrus pulp, beet pulp and distillers grains. The levels of feeding were 11 g DM per kg body weight and 17 g DM per kg body weight. Diets were offered in two equal feeds at 0800 h and 1400 h and after 14

days adaptation, nylon bags (50 µm pore size) containing 1.5 g ground test feed (2 mm screen) were incubated in duplicate for 0, 2, 4, 8, 14, 24 and 48 hours. After removal, the bags were stored at -20^{o}C until thawing, stomaching, machine washing, and measurement of residual DM, OM and CP. Disappearance of concentrates at each incubation time was expressed relative to the original feed which was non-incubated, non-stomached and non-washed. The exponential model of Orskov and McDonald (J. Agric. Sci (Camb) 92, 499-503, 1979) was used to measure the rate and extent of degradation according to the equation : $p = a+b\ (1-e^{-ct})$ where p = potential disappearance at time t, a = fraction of material that is water soluble, b = fraction that is potentially degradable in the rumen and c = rate of degradation of fraction b. Effective degradability (ED) was calculated as ED = a + (bxc)/(c+r), where r = fractional ruminal outflow rate per hour. An outflow rate of 0.05 was used.

In situ disappearance of Dry Matter (Table 3a)

There was no effect of diet or level of feeding on 'a', 'b', 'c' or ED of DM. There was a diet x level interaction for 'b' ($P<0.05$). The feed used had a significant effect on 'a', 'b', 'c' and ED ($P<0.001$). The 'a' value for soyahulls (SH) was the lowest of all feeds (mean 67g kg^{-1} DM), while that of maize gluten feed (MGF) was the highest (mean 394g kg^{-1} DM). The corresponding mean 'a' values for copra meal (CO), barley (BA), fish meal (FM) and soyabean meal (SBM) were 330, 387, 270 and 370g kg^{-1} DM respectively.

The 'b' value was greatest for SH, followed by FM, SBM, CO, MGF and BA respectively. The 'c' value of BA was higher than all other feeds examined ($P<0.05$) and the 'c' value of FM was lower than that of SBM ($P< 0.05$). On average, FM had the lowest ED of all feeds and BA had the highest (396 and 809g kg^{-1} DM respectively). The corresponding ED of CO, MGF, SH and SBM was 625, 680, 455 and 753g kg^{-1} DM respectively.

Table 3a **In situ disappearance of Dry Matter from concentrate feedstuffs at each diet and feeding level.**

Concentrate	F:C Ratio g kg^{-1}	Feeding Level 11g DM kg^{-1} BW a	b	c	ED	17g DM kg^{-1} BW a	b	c	ED
Copra meal	250-750	332	636	0.04	622	332	605	0.06	649
	500-500	347	593	0.05	632	323	633	0.04	608
	750-250	322	640	0.05	616	326	601	0.05	623
Maize gluten feed	250-750	390	571	0.05	674	392	564	0.06	688
	500-500	416	558	0.05	686	391	594	0.04	658
	750-250	401	599	0.05	685	376	557	0.07	689
Soya hulls	250-750	61	939	0.04	445	59	941	0.04	463
	500-500	68	861	0.03	456	77	924	0.03	447
	750-250	72	912	0.04	469	67	929	0.03	449
Barley	250-750	384	475	0.43	805	417	445	0.45	808
	500-500	445	417	0.46	813	345	501	0.52	799
	750-250	351	508	0.55	813	37.9	483	0.52	816
Fish meal	250-750	257	743	0.01	381	26.7	632	0.02	417
	500-500	290	710	0.01	409	25.4	746	0.01	378
	750-250	287	631	0.03	406	26.2	738	0.01	385
Soyabean meal	250-750	333	667	0.08	745	38.5	614	0.09	774
	500-500	413	585	0.08	758	39.7	604	0.07	740
	750-250	386	614	0.07	745	30.3	686	0.12	757

Test of Significance

	a		b		c		ED	
	Sig	**sed**	**Sig**	**Sed**	**Sig**	**sed**	**Sig**	**sed**
Diet	NS	11.7	NS	14.5	NS	0.012	NS	8.43
Level	NS	9.5	NS	11.9	NS	0.010	NS	6.89
Diet x Level	NS	16.5	*	20.4	NS	0.017	NS	11.93
Feed	***	14.6	***	20.6	***	0.020	***	6.87
Diet x Feed	NS	25.9	NS	35.4	NS	0.033	NS	13.75
Level x Feed	NS	21.1	NS	28.9	NS	0.027	NS	11.23
Diet x Level x Feed	NS	36.6	NS	50.1	NS	0.047	NS	19.44

F:C=Ratio of grass silage to concentrate offered in basal diet; 'a'=soluble fraction of feed DM as measured by washing loss from nylon bag; 'b'= potentially degradable fraction of feed DM; 'c'=rate of degradation of fraction 'b' (h^{-1}); ED=Effective rumen degradability of OM measured at outflow rate (k) of 0.05 h^{-1}

In situ disappearance of Nitrogen (N) (Table 3b)

There was no effect of diet or level of feeding on the ' a'of N. There was a diet x level interaction for ED ($P<0.05$). There were significant differences between feeds for 'a', 'b', 'c' and ED ($P<0.001$). On average, SH had the lowest 'a' value of all feeds examined and MGF had the highest (180 and 540g kg^{-1} N respectively). The 'a' values of all feeds were significantly different to each other apart from CO and FM and CO and SBM ($P<0.05$). The 'b' value of all feeds were significantly different to each other ($P<0.05$) apart from CO and SBM, CO and FM, CO and SH, SH and FM, FM and SBM. The 'c' value of all feeds were significantly different to each other apart from CO and SH, MGF and SBM and SH and FM. The ED of all feeds were significantly different to each other ($P<0.05$) except for MGF and BA.

In situ disappearance of Organic Matter (Table 3c)

There was no effect of diet or level of feeding on the 'a', 'b', 'c' or ED of OM, except for the significant effect of ratio of forage to concentrate on the ED value ($P<0.05$). The ED of OM was significantly greater ($P<0.05$) when offered a grass silage to concentrate ratio of 750:250 than when offered at a ratio of 250:750. From all feeds examined, SH had the lowest 'a' value and BA had the highest (120 and 350g kg^{-1} OM). The 'a' values of MGF, BA and SBM were not significantly different to each other (350, 350 and 330g kg^{-1} OM respectively). The 'b' value for OM was lowest for BA and highest for SH (500 and 890g kg^{-1} OM). The 'b' values of all feeds were significantly different to each other ($P<0.05$), apart from CO and SBM (670 and 660g kg^{-1} OM) and MGF and SBM (620 and 660g kg^{-1} OM) respectively. The 'c' value for OM was lowest for FM and highest for BA. The 'c' values of all feeds examined were significantly different to each other ($P<0.05$), apart from CO and MGF, CO and SH, MGF and SH, MGF and SBM, SH and FM. The ED of OM in all feeds were significantly different to each other ($P<0.05$).

Overall, this study showed that the basal diet can have a wide range in forage : concentrate ratio and level of feeding without having a biologically important effect on degradability.

Table 3b. In situ disappearance of Nitrogen from concentrate feedstuffs at each diet and feeding level

		Feeding Level							
	F:C Ratio	11g DM kg^{-1} BW				17g DM kg^{-1} BW			
Concentrate	g kg^{-1}	a	b	c	ED	a	b	c	ED
Copra meal	250-750	264	736	0.04	569	268	722	0.04	587
	500-500	277	720	0.04	565	256	744	0.03	524
	750-250	234	766	0.04	549	231	700	0.09	561
Maize gluten feed	250-750	536	443	0.09	797	537	450	0.08	798
	500-500	574	415	0.06	793	539	447	0.06	777
	750-250	547	452	0.06	786	530	436	0.09	799
Soya hulls	250-750	178	783	0.03	495	164	748	0.05	501
	500-500	157	774	0.04	489	205	703	0.04	498
	750-250	214	753	0.03	487	153	770	0.04	488
Barley	250-750	314	610	0.19	743	374	555	0.19	798
	500-500	439	485	0.19	809	263	621	0.30	786
	750-250	299	625	0.29	817	309	608	0.27	814
Fish meal	250-750	214	731	0.03	420	244	657	0.02	437
	500-500	267	733	0.01	418	220	780	0.01	383
	750-250	303	697	0.01	426	227	773	0.01	402
Soyabean meal	250-750	233	767	0.07	686	288	712	0.09	729
	500-500	316	683	0.07	709	317	682	0.06	682
	750-250	294	706	0.07	690	271	728	0.08	699

Test of Significance

	a		b		c		ED	
	Sig	**sed**	**Sig**	**Sed**	**Sig**	**sed**	**Sig**	**sed**
Diet	NS	13.4	NS	14.3	NS	0.007	NS	8.49
Level	NS	11.0	NS	11.7	NS	0.006	NS	6.93
Diet x Level	NS	19.0	NS	20.2	NS	0.010	*	12.00
Feed	***	18.1	***	19.0	***	0.013	***	10.08
Diet x Feed	NS	31.6	NS	33.2	NS	0.021	NS	18.06
Level x Feed	NS	25.8	NS	27.1	NS	0.017	NS	14.74
Diet x Level x Feed	NS	44.7	NS	47.0	NS	0.030	NS	25.54

F:C=Ratio of grass silage to concentrate offered in basal diet; 'a'=soluble fraction of feed N as measured by washing loss from nylon bag; 'b'= potentially degradable fraction of feed N; 'c'=rate of degradation of fraction 'b' (h-1); ED=Effective rumen degradability of N measured at outflow rate (k) of 0.05 h^{-1}

Table 3c. In situ disappearance of Organic Matter from concentrate feedstuffs at each diet and feeding level.

		Feeding Level							
	F:C Ratio	11g DM kg^{-1} BW				17g DM kg^{-1} BW			
Concentrate	g kg^{-1}	a	b	c	ED	a	b	c	ED
Copra meal	250-750	281	678	0.04	565	269	682	0.05	588
	500-500	282	688	0.04	583	269	671	0.05	594
	750-250	271	650	0.05	611	285	665	0.05	599
Maize gluten feed	250-750	343	624	0.05	639	354	609	0.05	652
	500-500	344	622	0.05	641	348	611	0.06	667
	750-250	345	607	0.06	675	341	635	0.06	689
Soya hulls	250-750	135	865	0.03	432	71.0	929	0.03	410
	500-500	108	892	0.03	441	146	878	0.03	467
	750-250	127	873	0.04	492	120	880	0.03	461
Barley	250-750	351	488	0.51	789	354	489	0.50	796
	500-500	329	518	0.42	788	385	473	0.48	812
	750-250	342	519	0.56	816	338	522	0.43	805
Fish meal	250-750	172	738	0.03	303	174	826	0.01	332
	500-500	191	724	0.01	331	193	807	0.01	355
	750-250	197	803	0.01	360	178	822	0.01	358
Soyabean meal	250-750	332	668	0.06	688	333	667	0.07	727
	500-500	339	657	0.08	725	365	635	0.08	754
	750-250	305	691	0.09	750	315	685	0.08	740
Test of Significance									
		a		**b**		**c**		**ED**	
		Sig	**sed**	**Sig**	**Sed**	**Sig**	**sed**	**Sig**	**sed**
Diet		NS	13.4	NS	14.3	NS	0.007	*	10.66
Level		NS	11.0	NS	11.7	NS	0.006	NS	8.70
Diet x Level		NS	19.0	NS	20.2	NS	0.010	NS	15.07
Feed		***	18.1	***	19.0	***	0.013	***	8.80
Diet x Feed		NS	31.6	NS	33.2	NS	0.021	NS	17.52
Level x Feed		NS	25.8	NS	27.1	NS	0.017	NS	14.31
Diet x Level x Feed		NS	44.7	NS	47.0	NS	0.030	NS	24.78

F:C=Ratio of grass silage to concentrate offered in basal diet; 'a'=soluble fraction of feed OM as measured by washing loss from nylon bag; 'b'= potentially degradable fraction of feed OM; 'c'=rate of degradation of fraction 'b' (h^{-1}); ED=Effective rumen degradability of OM measured at outflow rate (k) of 0.05 h^{-1}

Experiment 5. Digesta kinetics in steers offered diets varying in feeding level and the ratio of grass silage to concentrate

Degradability of protein feeds in the rumen is important when measuring protein supply in modern feed evaluation systems for ruminants. As shown in Experiment 4, the rate of outflow of protein supplements from the rumen has an impact on the effective degradation of feed and may be influenced by the composition of the diet and the amount of feed offered to the animal. As grass silage is the more commonly used forage in ruminant rations in European countries, there is a need to examine its effect on digesta passage. The objectives of this experiment were to measure the outflow rate of liquid and particulate matter from the rumen of steers offered diets varying in feeding level and ratio of grass silage to concentrate.

Digesta kinetics were measured simultaneously with the degradability measurements described in Experiment 4. A background sample of rumen fluid was taken before feeding (0h) at 0800h on day one of each measurement period before administration of Co-EDTA (a liquid phase marker) into the rumen via the cannula. Subsequent samples of rumen fluid were taken up to 48h post-administration. On day 1 of each measurement period, a background sample (0h) of faeces was taken from each animal. At feeding (0800h) on day one of each measurement period, the steers were dosed with Cr-mordanted pelleted concentrate (a particulate phase marker) via the ruminal cannula. Faecal grab samples were then taken for up to 120h post-dosing. The outflow rates of Co and Cr were estimated by regression of $\log_e$ (Co and Cr concentration) on time after dosing (Co) or peak excretion (Cr).

The outflow rate of liquid and particulate matter from the rumen is shown in Table 4. Increasing the proportion of grass silage in the diet resulted in a significant increase in the flow rate of liquid (Co) ($P<0.01$) but not of particulate matter (Cr) from the rumen.

The higher feeding level (L2), resulted in a higher rate of outflow of liquid (Co) and particulate matter (Cr) from the rumen (P<0.01). There was no significant diet by level interaction.

It is therefore important to consider the actual outflow rate of nutrients when measuring the feed value of individual concentrate ingredients. This will have an impact on the effective degradability and the relative nutritive values assigned to such ingredients.

Table 4. Outflow rate (h^{-1}) of liquid (Co) and particulate matter (Cr) in steers offered grass silage and pelleted concentrate at different ratios (D) and feeding levels (L)

Silage : Concentrate	Feeding level	Co	Cr	
D1	L1	0.0498	0.0344	
D2	L1	0.0542	0.0345	
D3	L1	0.0617	0.0342	
D1	L2	0.0582	0.0380	
D2	L2	0.0632	0.0442	
D3	L2	0.0698	0.0365	
	Sig (Co)	**s.e.d (Co)**	**Sig (Cr)**	**s.e.d. (Cr)**
Diet	**	0.030	NS	0.0021
Level	**	0.0025	**	0.0017
Diet *Level	NS	0.0043	NS	0.0029

**(P<0.01) NS = Not significant

D1, D2 and D3 = 250, 500 and 750g grass silage $DMkg^{-1}$ total diet respectively

L1 and L2 = 11g and 17g $DMkg^{-1}$ bodyweight respectively

Experiment 6. *In situ* ruminal degradability of concentrate ingredients commonly used in Ireland

The quantity of protein entering the small intestine of the ruminant is dependent on the degradability of feed protein in the rumen. The objective of this experiment was to measure the nitrogen and organic matter degradability of twelve different feeds in the rumen, using five different sources of each feed. The concentrate ingredients chosen represented those which are commonly used in Ireland. The feeds were classified as protein, energy or protein/energy feeds. The protein feeds used were sunflower meal (SUN), rapeseed meal (RAP), soyabean meal (SBM) and cottonseed meal (CSM). The energy sources used were palm kernel meal (PK), pollard (PO), barley (BA) and unmolassed beet pulp (BP). The protein/energy feeds used were distillers grains (MDG), corn gluten feed (MGF), copra meal (CO) and malt sprouts (MS).

Four Friesian steers were offered a diet consisting of silage and concentrate at a ratio of 50:50 and at 1.5% body weight on a DM basis at 8 am and 4 pm. Nylon bags, containing 1.5 g ground feed (2 mm screen), were heat sealed and incubated in duplicate in each animal for 0, 2, 4, 8, 14, 24 and 48 h. After removal the bags were stored at -20^{o}C until thawing, stomaching and machine washing.
Residual material was analysed for nitrogen and OM. The experiment consisted of three phases, viz. protein phase, energy phase, andprotein/energy phase when these classes of feeds were incubated. In each phase, the concentrate portion of the diet contained all the test feeds in addition to barley and unmolassed beet pulp. The parameters of digestion were estimated as described in Experiment 4 and ED for outflow rates of 0.02, 0.05, 0.06 and 0.08h^{-1} were calculated.

For the *in situ* degradability of N and OM in the protein feeds examined (SUN, RAP, SBM and CSM), the 'a', 'b' and 'c' values were significantly affected by the feed sample used ($P<0.05$ at least) for the

majority of feeds examined. The exceptions to this were for the 'b' value of RAP (ND and OMD), and the 'c' value of CSM (ND) which were unaffected by sample. The ED of N and OM in SBM was not significantly affected by sample used when calculated at k=0.02 h^{-1} but was significantly affected by sample ($P<0.05$ at least) for the other protein feeds examined when calculated at k=0.02, 0.05, 0.06 and 0.08 h^{-1} (Tables 5a, 5b).

For the *in situ* degradability of N and OM in the energy feeds examined (PK, PO, BA and BP), the 'a', 'b' and 'c' values were significantly affected by the feed sample used ($P<0.05$ at least) except for the 'b' value of PO (OMD), the 'c' value of all the test feeds (ND) and the 'c' value of PK (OMD). The ED of N and OM was significantly affected by sample of feed used for all the test feeds ($P<0.05$ at least) when calculated at all 'k' values with the exception of N, where the ED of PO for k=0.05, 0.06 and 0.08 h^{-1} and BA when calculated at k=0.08 h^{-1} were not significantly affected by the sample of feed used (Tables 5a, 5b).

For the *in situ* degradability of DM, N and OM in the protein + energy feeds examined (MGF, MDG, CO and MS), the 'a', 'b' and 'c' values were significantly affected by the feed sample used for the majority of test feeds ($P<0.05$ at least). The exceptions were for the 'a' value of MS (OM), the 'b' value of MGF, MDG and CO (OM) and CO (N). The 'c' value of MGF and CO (N) and MDG (OM) were not significantly affected by the sample of feed used. The ED of N and OM was significantly affected by sample of feed used ($P<0.05$ at least) when calculated at all 'k' values with the exception of EDDM for MGF and MS when calculated at k=0.02 h^{-1} (Tables 5a, 5b).

Table 5a. ***In situ*** **Nitrogen Degradability (g kg^{-1}) : Protein Feeds**

Feed	Sample	a[1]	b[1]	c[1]	ED[1]0.02	ED 0.05	ED 0.06	ED 0.08
Sunflower meal	1	418.8	479.3	0.377	873.4	841.0	831.2	812.9
Sunflower meal	2	404.4	503.7	0.449	885.2	854.6	845.3	827.9
Sunflower meal	3	476.1	475.4	0.249	912.3	865.1	851.7	827.6
Sunflower meal	4	462.1	482.8	0.194	898.0	843.0	827.7	800.6
Sunflower meal	5	199.9	760.7	0.072	787.4	641.1	607.6	554.1
Significance		***	***	***	***	***	***	***
s.e.d.		13.8	19.8	0.060	8.8	11.4	11.8	12.4
Rapeseed meal	1	288.4	606.0	0.126	811.6	722.4	699.1	659.3
Rapeseed meal	2	204.5	688.0	0.063	716.0	577.5	547.0	499.1
Rapeseed meal	3	211.2	611.0	0.112	725.6	627.7	603.0	561.5
Rapeseed meal	4	294.2	612.0	0.146	832.2	749.4	727.2	688.8
Rapeseed meal	5	273.5	617.0	0.087	771.5	661.3	634.8	591.5
Significance		***	NS	***	***	***	***	***
s.e.d.		12.0	37.3	0.012	18.0	14.8	14.6	14.2
Soyabean meal	1	135.3	857.0	0.166	898.5	791.3	762.1	710.8
Soyabean meal	2	162.5	816.0	0.141	874.9	761.7	731.7	679.9
Soyabean meal	3	171.3	763.0	0.144	832.1	724.6	696.5	648.5
Soyabean meal	4	147.1	767.0	0.189	834.2	742.8	717.7	673.6
Soyabean meal	5	30.7	948.0	0.108	824.5	670.6	632.0	567.4
Significance		***	***	*	NS	***	***	***
s.e.d.		11.0	35.2	0.022	26.9	21.0	20.2	19.4
Cottonseed meal	1	361.2	594.0	0.187	892.2	820.5	800.9	766.7
Cottonseed meal	2	337.6	569.0	0.156	840.3	765.8	745.7	710.8
Cottonseed meal	3	351.5	542.0	0.170	803.6	719.5	699.0	665.2
Cottonseed meal	4	277.1	638.0	0.090	781.1	665.4	638.4	594.9
Cottonseed meal	5	411.9	503.0	0.085	809.5	716.6	694.9	659.9
Significance		***	*	NS	**	***	***	**
s.e.d.		18.9	35.0	0.067	20.8	24.9	27.2	30.6

[1]a,b,c and ED are the fraction that is water soluble, the fraction that is potentially degradable in the rumen, the rate of degradation of b and an estimate of ruminal degradation at an assumed outflow rate, respectively.

Table 5a. (Continued) : Energy Feeds

Feed	Sample	a[1]	b[1]	c[1]	ED[1]0.02	ED 0.05	ED 0.06	ED 0.08
Palm kernel	1	41.1	922.0	0.031	573.6	373.0	336.5	283.5
Palm kernel	2	171.0	829.0	0.028	654.5	469.5	435.7	387.0
Palm kernel	3	260.7	739.0	0.020	624.3	467.6	441.6	405.3
Palm kernel	4	225.9	763.0	0.023	634.6	467.6	438.6	397.5
Palm kernel	5	83.8	873.0	0.022	542.3	351.6	319.0	273.0
Significance		***	***	NS	***	***	***	***
s.e.d.		11.7	34.6	0.005	17.9	18.7	18.1	16.9
Pollard	1	459.5	434.0	0.205	853.4	805.9	792.5	768.8
Pollard	2	512.6	398.0	0.211	873.7	830.1	818.0	796.3
Pollard	3	527.9	388.1	0.179	872.8	824.4	811.3	788.5
Pollard	4	501.3	410.7	0.209	870.1	822.2	809.1	786.0
Pollard	5	489.9	428.1	0.292	877.4	832.1	818.9	798.2
Significance		***	*	NS	***	NS	NS	NS
s.e.d.		8.0	12.2	0.062	4.4	11.6	13.5	16.5
Barley	1	291.0	641.4	0.363	893.1	843.4	828.9	802.2
Barley	2	319.8	592.7	0.417	881.1	840.5	828.3	805.8
Barley	3	263.5	669.5	0.435	900.3	857.2	844.2	819.9
Barley	4	273.3	631.3	0.271	858.4	800.9	784.3	754.1
Barley	5	333.1	626.2	0.218	904.7	839.1	820.6	787.4
Significance		***	**	NS	***	*	*	NS
s.e.d.		4.9	15.2	0.103	8.6	14.3	16.8	21.3
Beet pulp	1	133.1	857.2	0.061	754.6	579.0	541.4	483.0
Beet pulp	2	136.7	839.2	0.077	763.6	604.5	569.5	514.2
Beet pulp	3	69.5	918.0	0.043	711.4	514.0	472.7	409.3
Beet pulp	4	26.9	965.6	0.056	721.3	520.7	477.9	411.6
Beet pulp	5	511.2	475.0	0.095	892.7	808.7	788.8	756.3
Significance		***	***	NS	***	***	***	***
s.e.d.		15.0	13.7	0.017	21.9	30.4	30.7	30.1

Table 5a (Continued) : Protein + Energy Feeds

Feed	Sample	a[1]	b[1]	c[1]	ED[1]0.02	ED 0.05	ED 0.06	ED 0.08
Maize gluten	1	542.8	368.3	0.070	806.7	735.4	720.1	696.2
Maize gluten	2	728.3	247.3	0.043	888.2	834.9	824.4	808.7
Maize gluten	3	433.1	543.6	0.058	836.1	724.7	700.2	661.9
Maize gluten	4	392.8	504.4	0.063	750.4	650.4	629.2	596.2
Maize gluten	5	462.9	515.2	0.058	833.1	726.5	703.7	668.4
Significance		***	***	NS	***	***	***	***
s.e.d.		12.5	27.1	0.016	14.1	14.3	14.2	13.7
Maize distillers	1	296.5	322.0	0.118	567.3	516.2	503.3	481.7
Maize distillers	2	154.5	588.0	0.035	500.6	373.0	349.4	314.9
Maize distillers	3	39.7	991.0	0.015	319.8	173.9	154.2	128.3
Maize distillers	4	13.8	896.0	0.025	440.3	252.8	222.3	180.1
Maize distillers	5	81.8	447.0	0.033	359.0	259.0	240.0	212.2
Significance		***	***	***	***	***	***	***
s.e.d.		8.0	71.1	0.017	18.2	10.2	10.3	10.8
Copra meal	1	250.3	750.0	0.038	729.7	562.7	530.3	482.3
Copra meal	2	138.7	861.0	0.033	651.9	461.4	426.1	374.6
Copra meal	3	121.1	879.0	0.030	635.0	437.9	402.0	350.1
Copra meal	4	141.5	828.0	0.040	701.7	519.6	482.7	427.0
Copra meal	5	83.4	751.0	0.033	512.4	349.9	320.5	277.7
Significance		***	NS	NS	***	***	***	***
s.e.d.		15.0	71.0	0.007	27.2	16.0	14.4	12.2
Malt combings	1	394.2	491.3	0.050	742.5	638.2	616.2	582.4
Malt combings	2	385.4	493.5	0.058	753.2	652.4	630.1	595.2
Malt combings	3	439.7	413.2	0.040	776.5	663.3	640.9	607.4
Malt combings	4	480.5	424.5	0.050	784.0	693.5	674.3	644.7
Malt combings	5	440.1	413.3	0.075	767.9	690.3	672.0	642.4
Significance		***	**	**	*	***	***	***
s.e.d.		6.4	22.6	0.006	10.8	9.6	9.4	8.9

Table 5b ***In situ*** **Organic Matter Degradability (g kg^{-1}) : Protein Feeds**

Feed	Sample	a[1]	b[1]	c[1]	ED[1]0.02	ED 0.05	ED 0.06	ED 0.08
Sunflower meal	1	254.7	325.5	0.248	556.0	525.0	516.5	500.2
Sunflower meal	2	257.0	358.3	0.263	583.7	546.2	535.5	517.2
Sunflower meal	3	351.2	310.3	0.315	642.5	617.7	610.2	596.2
Sunflower meal	4	323.0	325.8	0.268	626.5	597.2	588.7	573.3
Sunflower meal	5	255.5	387.3	0.117	576.7	513.0	497.5	471.7
Significance		***	**	*	***	***	***	***
s.e.d.		6.6	15.9	0.055	8.6	7.2	7.7	8.8
Rapeseed meal	1	322.3	480.0	0.110	728.8	652.5	633.2	600.8
Rapeseed meal	2	251.0	470.8	0.068	615.0	523.0	501.7	468.0
Rapeseed meal	3	278.8	476.3	0.070	649.5	557.2	535.5	501.3
Rapeseed meal	4	309.3	505.0	0.110	736.3	655.8	635.5	600.8
Rapeseed meal	5	306.5	503.0	0.100	721.5	636.0	615.2	580.3
Significance		***	NS	*	***	***	***	***
s.e.d.		9.3	20.1	0.014	12.6	11.5	11.4	11.7
Soyabean meal	1	324.3	633.8	0.170	890.0	811.8	790.3	753.0
Soyabean meal	2	350.5	625.0	0.125	889.8	797.8	773.5	732.5
Soyabean meal	3	354.3	627.0	0.113	884.0	784.3	759.0	717.0
Soyabean meal	4	319.5	669.8	0.100	873.0	759.5	731.8	685.5
Soyabean meal	5	287.5	706.3	0.095	869.3	748.5	718.8	669.0
Significance		***	**	***	NS	***	***	***
s.e.d.		9.6	17.2	0.013	9.6	10.9	11.5	12.0
Cottonseed meal	1	415.8	470.0	0.095	801.8	720.5	700.8	668.0
Cottonseed meal	2	317.5	414.0	0.085	649.8	574.8	557.0	528.0
Cottonseed meal	3	298.5	587.0	0.048	696.8	569.8	544.0	505.0
Cottonseed meal	4	259.2	493.0	0.063	631.5	531.5	509.2	473.8
Cottonseed meal	5	328.7	461.0	0.038	685.5	561.0	536.5	501.3
Significance		***	**	**	***	***	***	***
s.e.d.		11.0	37.0	0.013	14.3	13.8	13.9	13.9

[1]a,b,c and ED are the fraction that is water soluble, the fraction that is potentially degradable in the rumen, the rate of degradation of b and an estimate of ruminal degradation at an assumed outflow rate, respectively.

Table 5b (Continued) : Energy Feeds

Feed	Sample	a[1]	b[1]	c[1]	ED[1]0.02	ED 0.05	ED 0.06	ED 0.08
Palm kernel	1	49.1	884.0	0.030	567.2	371.3	335.4	283.3
Palm kernel	2	182.1	797.0	0.028	639.3	464.5	432.9	387.1
Palm kernel	3	189.2	758.0	0.028	624.8	458.6	428.4	384.8
Palm kernel	4	214.4	724.0	0.028	621.6	463.1	434.7	393.9
Palm kernel	5	68.5	891.0	0.035	630.5	431.4	393.2	336.7
Significance		***	**	NS	*	***	***	***
s.e.d.		10.6	44.1	0.006	21.3	18.6	17.5	15.5
Pollard	1	376.9	385.1	0.080	684.1	612.9	596.0	568.5
Pollard	2	428.3	354.5	0.123	731.6	677.9	664.1	640.6
Pollard	3	415.6	359.5	0.090	709.4	646.3	630.9	605.6
Pollard	4	453.4	349.9	0.098	740.6	681.2	666.6	642.7
Pollard	5	417.7	374.0	0.118	735.7	677.7	662.9	637.8
Significance		***	NS	*	***	***	***	***
s.e.d.		8.3	12.6	0.014	6.7	8.1	8.4	8.8
Barley	1	253.3	609.5	0.723	844.0	818.1	810.0	794.6
Barley	2	291.1	581.0	0.443	845.4	810.0	799.2	779.0
Barley	3	318.9	600.4	0.458	894.0	859.8	849.3	829.4
Barley	4	239.7	633.6	0.368	839.8	795.8	782.6	758.0
Barley	5	320.1	564.5	0.883	871.1	852.1	846.1	834.5
Significance		***	***	*	***	***	***	***
s.e.d.		5.4	10.1	0.139	7.5	8.7	9.6	11.6
Beet pulp	1	142.3	783.0	0.133	820.0	706.6	676.8	626.0
Beet pulp	2	223.6	729.7	0.115	839.2	724.1	695.0	646.2
Beet pulp	3	117.5	832.5	0.093	804.2	661.5	626.3	568.0
Beet pulp	4	162.3	795.0	0.090	814.3	674.8	640.9	585.0
Beet pulp	5	532.6	435.5	0.185	921.9	869.2	854.8	829.5
Significance		***	***	***	***	***	***	***
s.e.d.		17.5	30.7	0.018	17.0	16.5	16.4	16.1

Table 5b (Continued) : : Protein + Energy Feeds.

Feed	Sample	a[1]	b[1]	c[1]	ED10.02	ED 0.05	ED 0.06	ED 0.08
Maize gluten	1	436.6	563.4	0.028	760.5	636.3	613.8	581.2
Maize gluten	2	464.2	534.4	0.033	787.3	668.1	645.9	613.4
Maize gluten	3	401.6	568.7	0.045	793.0	669.8	644.5	606.0
Maize gluten	4	406.2	564.5	0.038	767.5	642.3	617.9	581.8
Maize gluten	5	409.6	537.3	0.055	803.0	691.6	667.4	629.8
Significance		***	NS	**	*	***	***	***
s.e.d.		4.7	21.0	0.006	11.7	10.5	10.2	9.4
Maize distillers	1	412.0	471.0	0.040	714.1	612.3	592.4	562.7
Maize distillers	2	329.5	583.0	0.033	675.9	547.4	523.7	489.1
Maize distillers	3	293.9	560.0	0.023	609.5	485.1	462.9	431.1
Maize distillers	4	297.2	604.0	0.033	626.3	500.7	478.3	446.1
Maize distillers	5	281.6	548.0	0.043	610.1	494.7	473.1	441.1
Significance		***	NS	NS	***	***	***	***
s.e.d.		14.4	71.9	0.013	17.7	9.7	9.9	10.3
Copra meal	1	375.5	549.4	0.055	770.6	656.5	632.1	594.4
Copra meal	2	350.0	527.9	0.045	717.7	603.7	580.1	544.0
Copra meal	3	359.7	589.6	0.053	775.9	652.1	626.0	586.0
Copra meal	4	359.5	551.5	0.080	791.6	687.9	663.8	625.1
Copra meal	5	325.5	606.0	0.050	739.6	611.3	585.0	544.9
Significance		*	NS	*	***	***	***	***
s.e.d.		11.3	25.8	0.010	8.4	10.0	10.2	9.9
Malt combings	1	363.3	456.8	0.035	649.3	550.6	531.6	503.4
Malt combings	2	353.7	575.4	0.030	684.7	559.7	537.0	503.9
Malt combings	3	372.9	515.0	0.033	672.2	561.3	540.9	511.2
Malt combings	4	381.4	408.2	0.058	677.4	592.7	574.5	546.2
Malt combings	5	365.7	440.5	0.058	683.0	591.6	572.1	541.8
Significance		NS	***	***	***	***	***	***
s.e.d.		8.5	28.9	0.004	5.5	5.4	5.6	5.9

Almost all degradability parameters examined in the current study were influenced by sample of feed within different feed classes. The nutritive value of any particular concentrate ingredient cannot be assumed to be constant. Feeds with lower ruminal degradability values are used in ruminant diets to either increase the total protein supply to the small intestine or to modify the amino acid profile available for absorption in the small intestine. Such efforts could be futile because of variation of individual sample values from the mean value. Ruminal degradation and intestinal digestion of different feeds and different samples of these feeds should be measured to guarantee nutrient supply.

Experiment 7. Determination of the small intestinal digestibility of individual concentrate ingredients using *in vitro* and *in vivo* techniques

Compared to ruminal degradability, little information is available regarding the subsequent intestinal digestibility of the feed protein fraction in the small intestine (SID). As *in vivo* measurement requires the use of surgically prepared animals which is expensive and labour intensive, more rapid and cost effective methods of assessing SID have been developed. The objectives of this study were (1) to measure the SID of different sources of the range of concentrate feedstuffs described in Experiment 6, using an *in vitro* and *in vivo* technique and (2) to compare the results obtained using both methods.

Five sources of each of twelve different feedstuffs representing either protein, energy or protein+energy classes were used. To obtain the feed protein residue, four Friesian steers which were 1.5 to 2 years old and weighed 391 (sd 23.4kg) at the start of the experiment were used. The experiment consisted of three blocks, where the first block contained the protein classes, the second contained the energy classes and the third contained the protein+energy classes. The degradability of the protein classes were measured in all 4 animals in the first period of the experiment with the energy and protein+energy classes being measured in the second and third periods, respectively.

The animals were offered 500g grass silage DM per kg total diet and 500g concentrate DM per kg total diet at a feeding level of 15g DM per kg body weight in two equal feeds at 0800h and 1600h. The concentrate portion of the diet contained the test feeds, whose SID was measured, in addition to BA and BP. The test protein feeds were SUN, RAP, SBM and CSM. The test energy feeds were PK, PO, BA and BP. The test protein-energy feeds were MDG, MGF, CO and MS. The *in vitro* method was based on digestion by pepsin-pancreatin. Thus, 2 lactating Friesian cows were surgically prepared with a T-piece duodenal cannula. Residues remaining after ruminal incubation for 16h were pooled from the four steers and 1g of pooled residue was incubated in duplicate in the small intestine of each cow. Bags were introduced via the duodenal cannula and subsequently recovered in the faeces. Following recovery, the bags were machine washed and dried at 480C. To calculate the *in vitro* and *in vivo* digestibility of the feedstuffs, the nitrogen (N) content of the residue was measured before and after SID measurements.

The SID of concentrate ingredients measured by *in vitro* and *in vivo* procedures is shown in Table 6. The *in vivo* SID of CSM, SBM, SUN, PK, CO, MDG, MGF ($P<0.001$) and MS ($P<0.05$) *were* significantly affected by source of ingredient. The *in vivo* SID of RAP, BA and BP was not significantly affected by source of ingredient. The *in vitro* SID of RAP, SBM, SUN, BA, BP, PK, CO, MDG, MGF, MS ($P<0.001$) and CSM ($P<0.01$) were significantly affected by source of ingredient used. The SID of PO is not reported due to analytical difficulties encountered using the *in vitro* technique. The SID of concentrate ingredients within protein, energy and protein+energy classes is shown in Table 7. The SID of concentrate ingredients were significantly different to each other within each concentrate type ($P<0.05$). The relationship between *in vivo* (Y) and *in vitro* (X) SID of the concentrate ingredients is described by the equation $Y = -9.19+1.27X$ ($R=0.91$).

Table 6. Small intestinal digestibility (%) of different sources of concentrate ingredients using an *in vitro* (pepsin-pancreatin digestion) and *in vivo* (mobile nylon bag) procedure.

Concentrate	Feed Type	Method	Source 1	Source 2	Source 3	Source 4	Source 5	Sig	s.ed.
Cottonseed meal	Protein	*In vivo*	90.4	73.7	84.6	85.1	83.4	***	1.43
		In vitro	71.5	59.1	68.9	65.2	55.9	**	4.54
Rapeseed meal	Protein	*In vivo*	76.5	69.0	74.5	64.6	71.1	ns	4.52
		In vitro	61.9	60.1	66.5	55.5	66.0	***	1.68
Soyabean meal	Protein	*In vivo*	98.3	98.4	97.2	96.6	98.5	***	0.22
		In vitro	85.6	81.7	88.0	82.1	82.8	***	1.48
Sunflower meal	Protein	*In vivo*	56.6	45.5	42.8	62.7	85.4	***	3.69
		In vitro	61.5	46.0	46.6	64.8	83.8	***	1.78
Barley	Energy	*In vivo*	56.1	41.9	34.8	39.9	40.8	ns	8.02
		In vitro	48.6	40.8	45.0	41.0	47.3	***	1.12
Beet pulp	Energy	*In vivo*	72.4	71.2	72.7	67.0	72.6	ns	2.36
		In vitro	60.2	60.2	58.6	58.8	62.8	***	1.03
Palm kernel meal	Energy	*In vivo*	79.5	76.0	68.1	82.1	78.1	***	1.46
		In vitro	67.5	70.2	54.5	60.7	67.0	***	1.24
Copra meal	Prot-Energy	*In vivo*	81.6	78.2	78.9	87.8	81.7	***	1.48
		In vitro	65.7	62.6	68.0	80.5	66.4	***	1.84
Maize distillers	Prot-Energy	*In vivo*	75.0	87.2	91.1	83.4	93.5	***	3.42
		In vitro	69.6	76.5	78.0	69.3	84.3	***	2.07
Maize gluten feed	Prot-Energy	*In vivo*	69.6	65.6	65.6	55.0	72.1	***	2.31
		In vitro	64.5	60.2	71.7	50.7	69.6	***	1.6
Malt sprouts	Prot-Energy	*In vivo*	55.4	47.3	52.2	53.9	46.1	*	2.7
		In vitro	52.4	48.6	50.3	51.6	48.9	***	1.34

*(P<0.05), **(P<0.01), ***(P<0.001) ns =)Not significant

Table 7. Comparison of small intestinal digestibility (%) (SID) of concentrate ingredients within protein, energy and protein+energy feeds using an *in vitro* (pepsin-pancreation digestion) and *in vivo* (mobile nylon bag) procedure

						Sig	s.e.d
Protein	In *vivo*	58.6 SUN	71.1 RS	97.8 SBM	83.4 CSM	*	5.91
	In *vitro*	60.5 SUN	62.0 RS	84.0 SBM	64.1 CSM	*	5.58
Energy	In *vivo*	42.7 BA	76.7 PK	NR PO	71.2 BP	*	3.60
	In *vitro*	44.5 BA	63.9 PK	NR PO	60.1 BP	*	2.72
Protein-Energy	In *vivo*	81.6 CO	65.5 MGF	86.0 MDG	51.0 MS	*	3.56
	In *vitro*	68.6 CO	63.3 MGF	75.5 MD	G50.3 MS	*	3.99

*(P<0.05)
SUN = Sunflower meal RS = Rapeseed meal SBM = Soyabean meal CSM = Cottonseed meal BA = Barley
PK=Palm kernel meal PO = Pollard BP = Beet Pulp CO = Copra meal MGF = Maize gluten feed
MDG = Maize distillers grains MS = Malt sprouts NF = Not reported

Within most concentrate ingredients examined, the variation in SID due to source indicates a range in the quantity of amino acids supplied to the animal for productive purposes. As there is a good relationship between SID results obtained *in vitro* and those obtained *in vivo* for the ingredients examined in this study, the more rapid and cost effective *in vitro* technique can be used routinely to screen the SID of concentrate ingredients. However, the *in vitro* SID technique requires further work where feeds like PO that have a high fibre and low N content are concerned.

Experiment 8. Ruminal volatile fatty acid concentrations in steers offered individual concentrate ingredients

To develop feed systems based on absorbed nutrient supply, quantitative relationships between ruminal volatile fatty acid (VFA) production and feed chemical composition need to be examined. The objectives were to measure VFA produced from diets containing a high proportion of individual concentrate ingredients. In Experiment 8a, six Friesian steers were assigned at random to six feeds in an incomplete (4 periods), 6 (animals) by 6 (periods, 23 days adaptation) Latin Square experiment. The feeds were copra meal (CM), sunflower meal (SM), corn gluten feed (Archer Daniels Midland Company) (ADM), corn gluten feed (Cargill) (CAR), soya hulls (SH) and palm kernel meal (PK). Feeds were offered in two equal portions at 0830 h and 1430 h at approximately twice maintenance metabolisable energy allowance and at a hay-to-concentrate ratio of 15:85. Rumen fluid was collected using a naso-ruminal sampling device at 0800, 1030, 1430, 1630 and 2030 h. Individual VFA concentration (mmol/l) and VFA as a percentage of total VFA (PVFA) are show in Table 8a.

Table 8a. Concentration (mmol/l)[1] and proportions (g/kg)[2] of volatile fatty acids in rumen fluid

	Ingredient							
	Copra meal	Sunflower meal	ADM gluten	Cargill gluten	Soya hulls	Palm kernel	s.e.d.	Significance
Acetate[1]	32.0	34.5	26.0	31.7	47.7	30.2	4.2	*
Propionate[1]	9.1	9.0	10.9	13.1	11.6	6.4	1.9	*
Butyrate[1]	6.6	5.0	4.9	5.2	5.8	4.9	1.1	NS
Total[1]	49.2	51.5	43.7	51.8	66.1	44.3	6.7	*
Acetate[2]	654	673	608	617	722	683	21.1	***
Propionate[2]	180	173	238	250	176	146	22.1	**
Butyrate[2]	138	117	114	105	89	115	11.5	*

Table 8b. Concentration (mmol/l)[1] and proportions (g/kg)[2] of volatile fatty acids in rumen fluid

	Ingredient					
	Sugar beet pulp	Rolled barley	Citrus pulp	Molasses	s.e.d.	Significance
Acetate[1]	54.0	47.5	38.3	22.7	5.01	*
Propionate[1]	13.9	18.3	7.8	6.2	1.63	*
Butyrate[1]	8.6	9.1	10.8	15.4	2.28	NS
Total[1]	77.4	77.5	57.7	45.0	2.8	*
Acetate[2]	699	613	669	511	76.0	*
Propionate[2]	178	235	134	140	18.8	*
Butyrate[2]	11	12	19	33	19.0	*

In Experiment 8b, rolled barley, citrus pulp, sugar cane molasses and unmolassed beet pulp were fed to 4 ruminally fistulated steers in a four (ingredients) by four (periods) Latin Square experiment. Feeds were offered in two equal portions at 0830h and 1430h at approximately twice maintenance metabolisable energy allowance and at hay-to-concentrate ratio of 15:85. Ruminal fluid was collected at 0800, 1000, 1200, 1400, 1600, 1800 and 2000h. The concentration and proportions of VFA are shown in Table 8b.

Marked differences were observed in the VFA pattern between individual concentrate ingredients, likely reflecteing the differences in the substrates supplied by each feedstuff to the ruminal micro-organisms. Feed had a significant effect on acetic acid PVFA ($P<0.001$), acetic acid, propionic acid PVFA ($P<0.01$), propionic acid, and butyric acid PVFA ($P<0.05$). High-fibre and high-starch concentrates result in a high concentration and proportion of acetic acid and propionic acid respectively.

It is concluded that target VFA concentrations and proportions may be produced by varying the proportions of the individual ingredients in a concentrate ration.

Experiment 9. *In vitro* production of volatile fatty acids and methane from individual feed ingredients by ruminal microorganisms

Future feed systems are likely to be based on absorbed nutrient supply and will need to accomodate the range in VFA produced from individual ration ingredients. Measurement of VFA production *in vivo* is technically difficult. While *in vivo* ruminal concentrations of VFA can be predicted with some accuracy from the chemical composition of individual ingredients, concentrations represent a balance, at any sampling time, between the competing processes of production, passage and absorption from the rumen. Use of feed composition to predict VFA supply is likely therefore to have limited applicability. *In vitro* techniques allow measurement of VFA yield with greater convenience and control than *in vivo* procedures.

The production of methane, which represents an energy loss to the ruminant and is a pollutant of the environment, is similarly not readily measured *in vivo* but can be measured in closed *in vitro* systems.

The objectives of this study were to measure the production of individual VFA and gases during *in vitro f*ermentation of a range of feed ingredients.

Twelve different ingredients and two sources of two ingredients, which are commonly used in ruminant rations in Ireland, were examined. They represented a range in fibre, starch, sugar and protein concentrations. For measurement of VFA production, 1g of non-dried (1.15 g sugar cane molasses to allow for lower dry matter concentration than "dry" concentrates) were incubated in duplicate *in vitro* in non-gastight incubation vessels (final culture volume = 100 ml). Samples (1 ml) of vessel contents were removed at intervals up to 72 h for measurement of VFA by gas chromatography. This procedure was replicated twice. In parallel, 1 g samples (or equivalent) were incubated in duplicate in gastight vessels. Gas was removed at intervals, the volume recorded and composition determined by gas chromatography.

This procedure was replicated twice. The inoculum used was prepared from pooled rumen contents of 3 steers offered 1 kg straw and 8 kg of a concentrate ration daily. Cumulative VFA and gas production data, corrected for fermentation of residual feed in the inoculum, were subjected to analysis of variance using a model that had feed and replicate as sources of variation. End-products of ruminal fermentation are summarised in Table 9.

The *in vitro* procedure used, allowed VFA production to be measured across a large range of feeds under standardised conditions. The quantitative data generated in this type of study will be of value when calculating total VFA available for absorption from the rumen from various rations offered *in vivo*. The gas production data indicate that on average, 75% of gas produced during ruminal fermentation consists of carbon dioxide. The variation in methane production among individual concentrate ingredients however provides an opportunity to formulate rations to minimize environmental pollution with methane.

Table 9. Individual VFA (mmol/l) produced during 44 h of fermentation and cumulative total gas, methane and carbon dioxide (ml) produced during 48 h of fermentation of individual feed ingredients.

	Acetate	Propionate	Butyrate	Gas	Methane	Carbon Dioxide
Rolled barley source1	35.1	7.1	13.7	257	23.1	212.3
Rolled barley source2	35.3	7.8	13.7	258	22.9	212.8
Citrus pulp	43.1	13.3	8.3	252	21.8	211.5
Sugar beet pulp	40.3	12.8	8.0	270	21.8	226.9
Sugar cane molasses	30.3	14.4	5.6	201	15.0	169.5
Copra meal	28.8	11.1	6.0	191	18.3	156.3
Sunflower meal	18.0	6.4	2.4	112	9.1	92.6
Corn gluten source1	27.3	11.0	4.6	214	18.2	181.1
Corn gluten source2	28.4	13.1	5.4	198	16.5	164.6
Soyahulls	45.1	15.8	4.1	286	28.1	234.8
Palm kernal	15.0	3.7	3.7	160	14.9	130.7
Ground barley	38.0	8.8	12.9	263	24.6	215.6
Rolled wheat	39.1	11.1	13.8	281	25.9	231.3
Ground wheat	36.7	11.7	12.0	277	26.4	227.4
S.e.d.	3.53	2.05	1.33	7.81	1.02	6.86
Significance	**	**	**	**	**	**

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the considerable assistance of many colleagues in this project, in particular the technical, farm and clerical staff at Grange Research Centre. Aiveen Marron and Vincent McHugh, together with the staff of Grange Laboratories and other technical staff at Grange provided a vital, skilled contribution. Similarly, Grange farm and service staff willingly undertook considerable work in the animal-related research in this project. Mary Smith and Ann Gilsenan always provided clerical support to a very high standard.

The co-operation of Dr. N. Scollan, Institute for Grassland and Environmental Research, Aberystwyth, Wales and Dr. S. Calsamiglia, Universitat, Autonoma de Barcelona, Spain in facilitating visits by V. Woods to their respective institutions is gratefully acknowledged.

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